STAR
Heavy Ion Physics

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Outline

(1) STAR Physics Programs

(2) Selected Results from RNC

- **Partonic collectivity and EoS at RHIC[(a)]**
- Preparation for BES — G. Odyniec
- Heavy flavor — X. Dong
- Jet reconstruction — M. Polkson
- HFT — H. Wieman

Physics Goals at RHIC

RHIC

Au+Au Cu+Cu
d+Au p+p

200 – 5 GeV

Polarized p+p
200 & 500 GeV

p+p d+Au
pp2pp

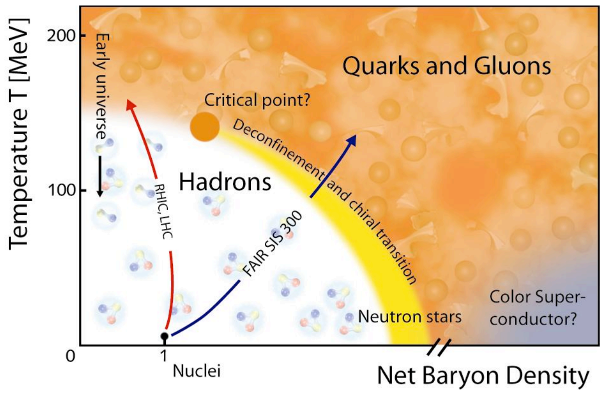
- Identify and study the property of matter (EOS) with partonic degrees of freedom.

- Explore the QCD phase diagram.

- Study the origin of spin in *p*.

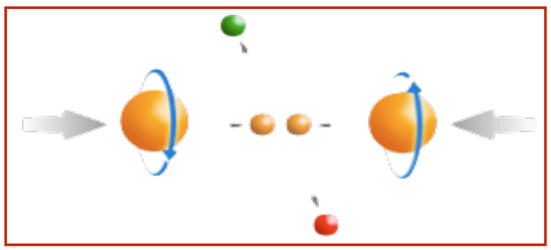
- Investigate the physics at small-*x*, gluon-rich region.

STAR Physics Focus

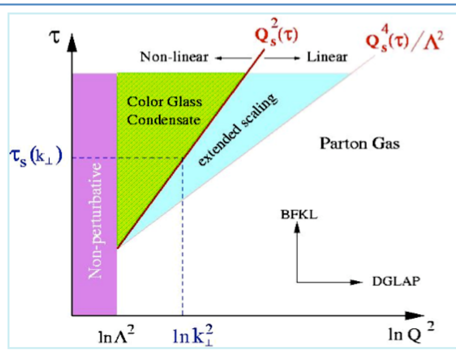


1) At 200 GeV top energy
- Study ***medium properties, EoS***
- pQCD in hot and dense medium

2) RHIC beam energy scan
- Search for ***critical point***
- Chiral symmetry restoration

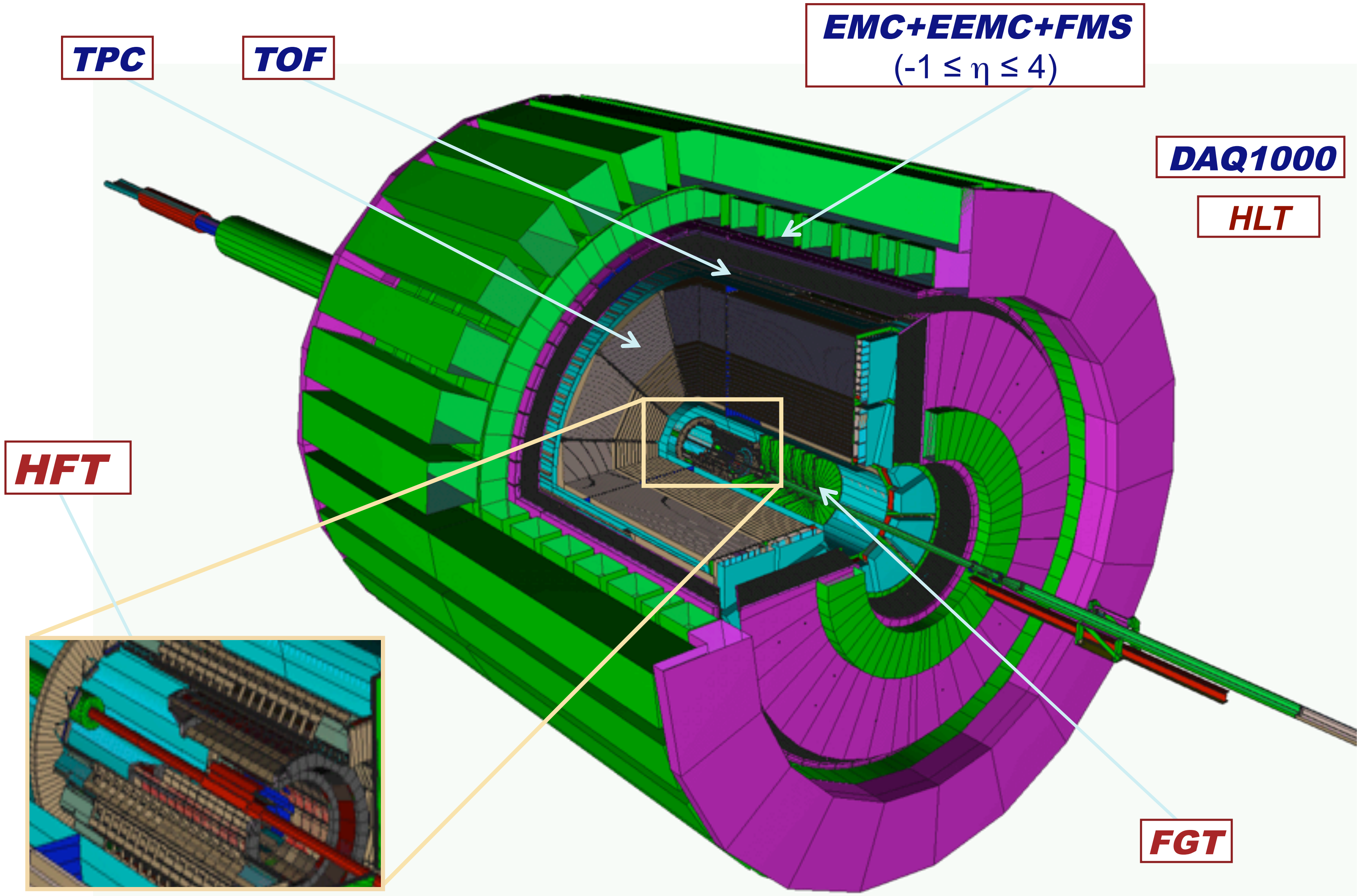


Polarized spin program
- Study ***proton intrinsic properties***

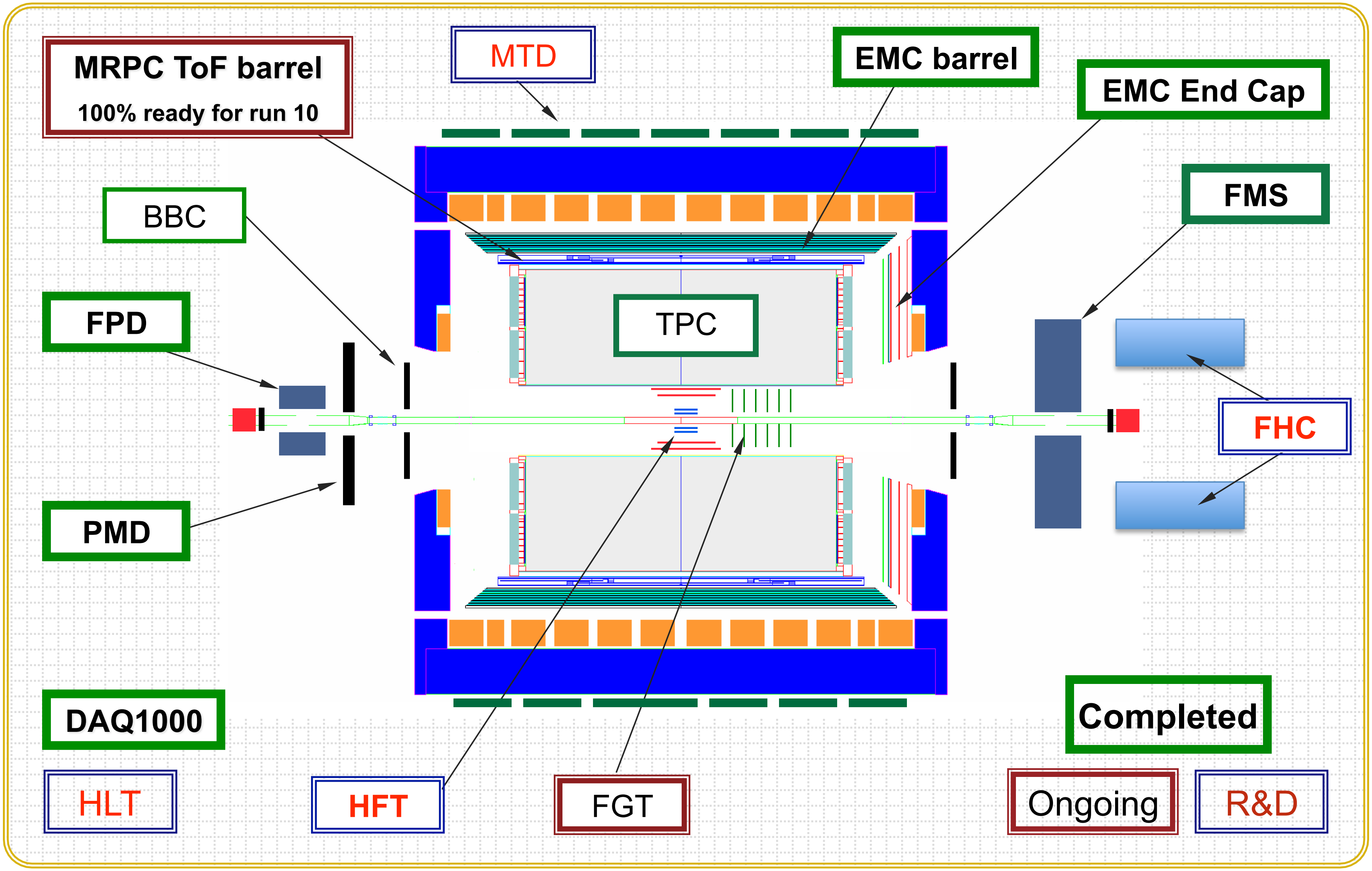


Forward program
- Study low-x properties, search for ***CGC***
- Study elastic (inelastic) processes (pp2pp)
- Investigate ***gluonic exchanges***

STAR Detectors: *Full 2π particle identification!*



STAR Detector

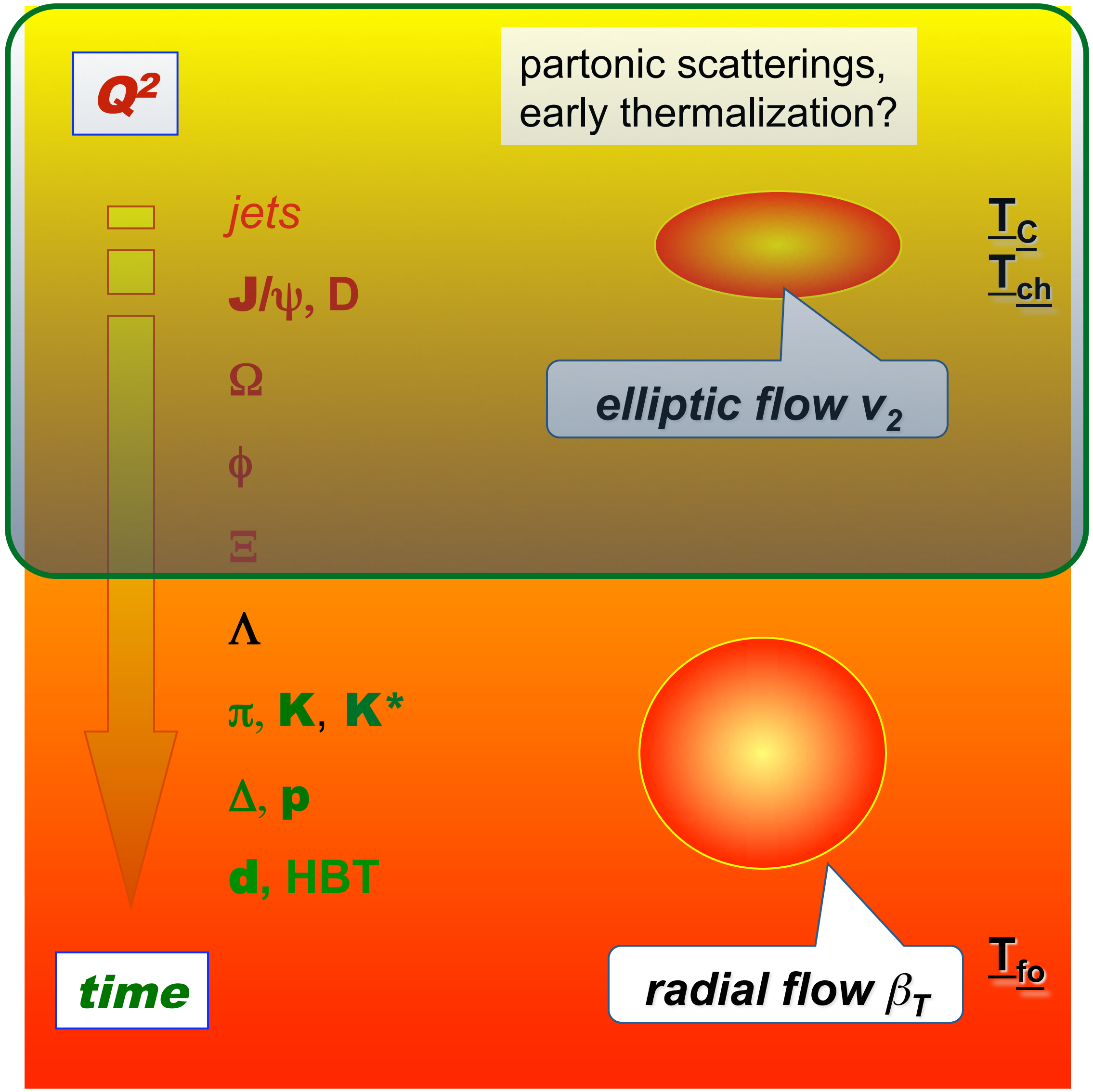


High-energy nuclear collisions

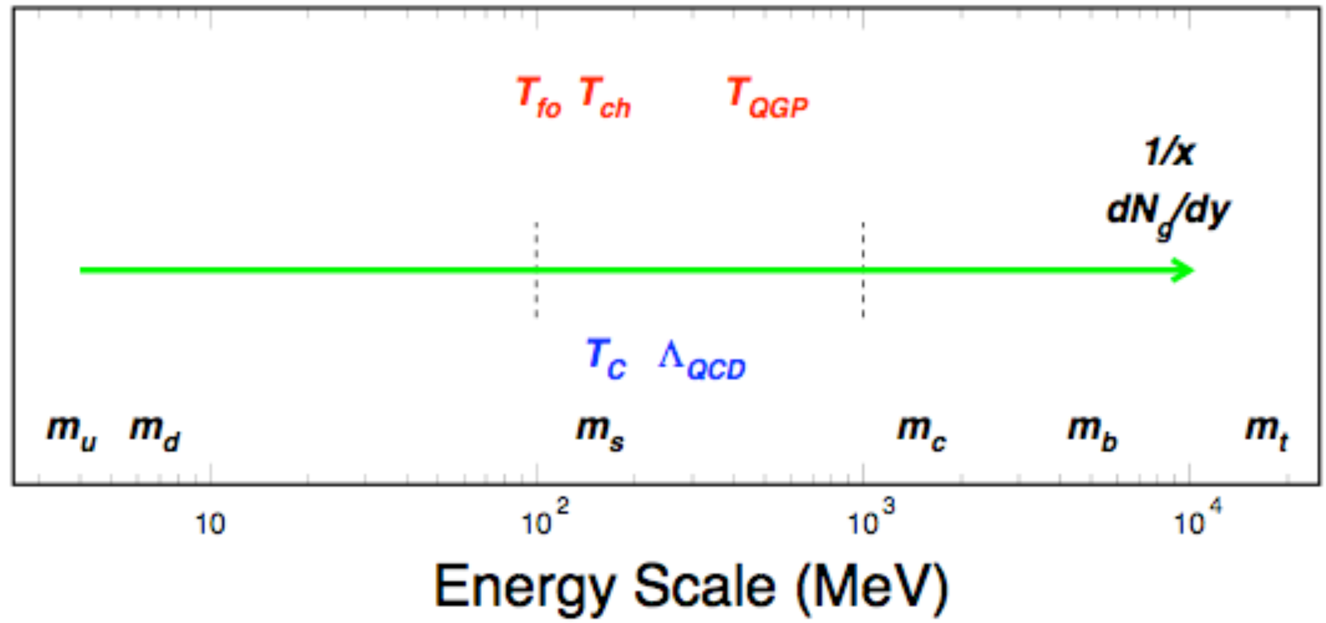
Initial Condition
- **initial scatterings**
- **baryon transfer**
- **E_T production**
- **parton dof**

System Evolves
- **parton interaction**
- **parton/hadron expansion**

Bulk Freeze-out
- **hadron dof**
- **interactions stop**



QCD Energy Scale

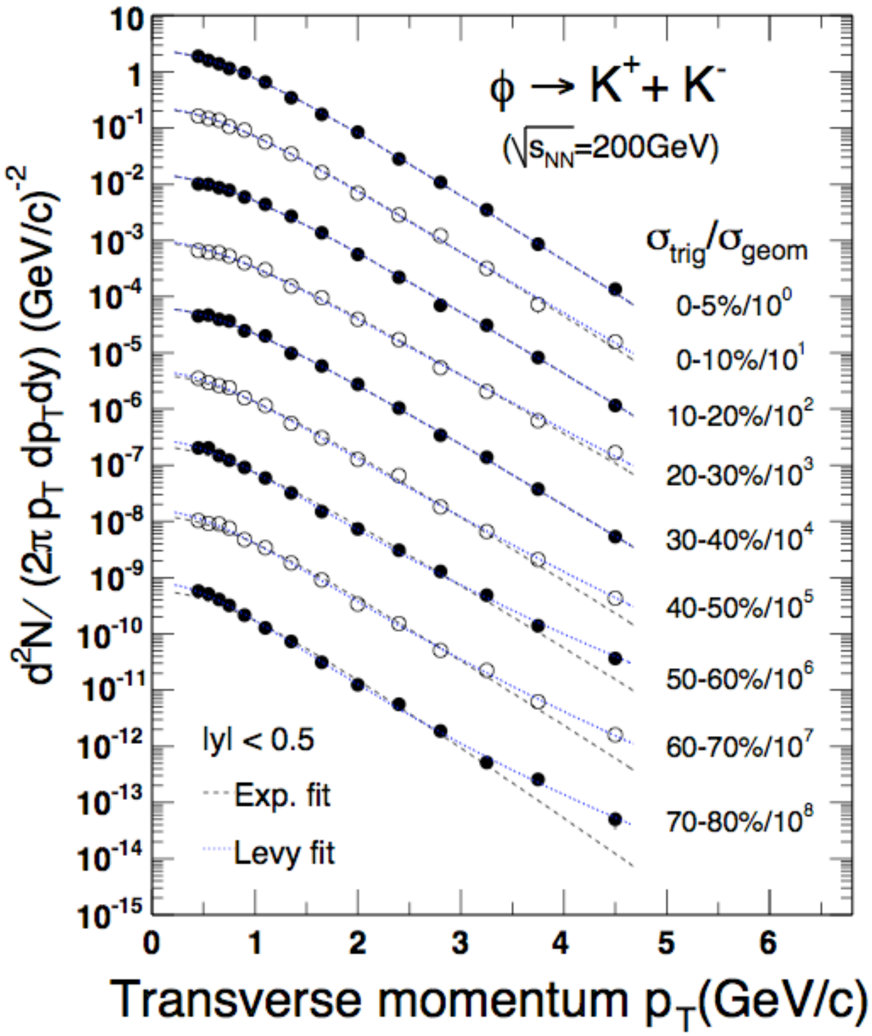


m_s ~ 0.2 GeV, similar to values T_C critical temperature Λ_{QCD} QCD scale parameter T_{CH} chemical freeze-out temperature $\Lambda_\chi = 4\pi f_\pi$ scale for χ symmetry breaking	m_c ~ 1.2 - 1.5 GeV >> Λ_{QCD} - pQCD production - parton density at small-x - QCD interaction - medium properties R_{cc} ~ $1/m_C$ => color screening J/ψ => deconfinement and thermalization
u-, d-, s-quarks: ***light-flavors***	c-, b-quarks: ***heavy-flavors***

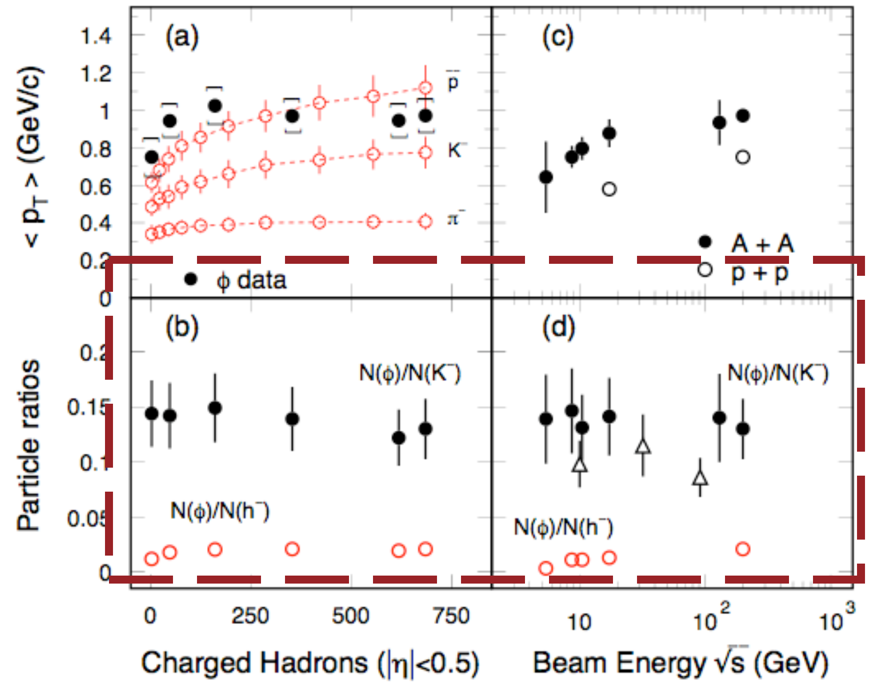
Strange-quark ⇒ hadronization
partonic collectivity

Charm-quark ⇒ thermalization

ϕ-meson from Au+Au Collisions



*STAR: nucl-ex/0703033; PRL **99**, 112301(07)*

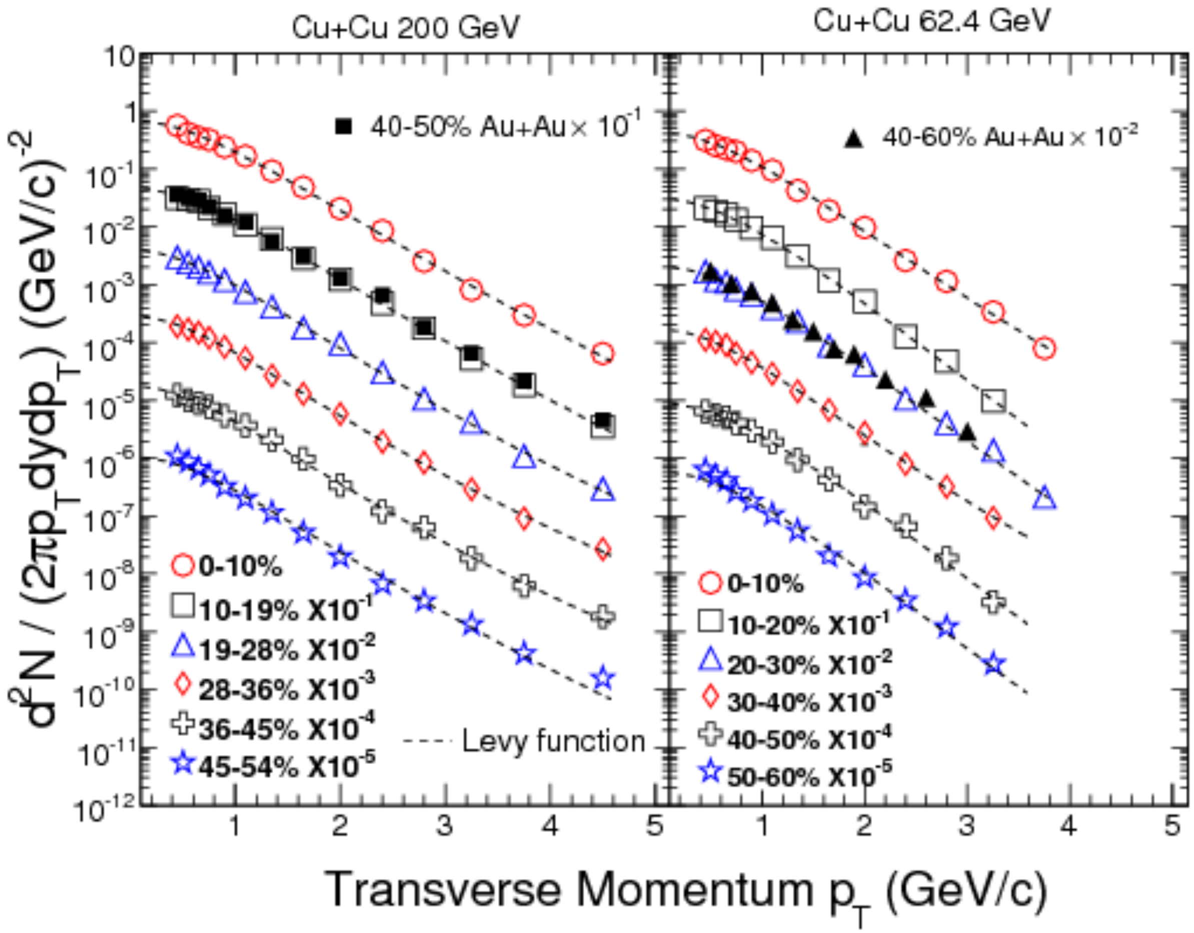


The ratios N(ϕ)/N(K) independent of systematic size, nor the collision energy In the coalescence model, the ratio increase as collision energy as K yields increases.

The ss fusion ⇨ ϕ-meson formation!

STAR: Phys. Lett. B612, 81(2005)

ϕ-meson from Cu + Cu Collisions



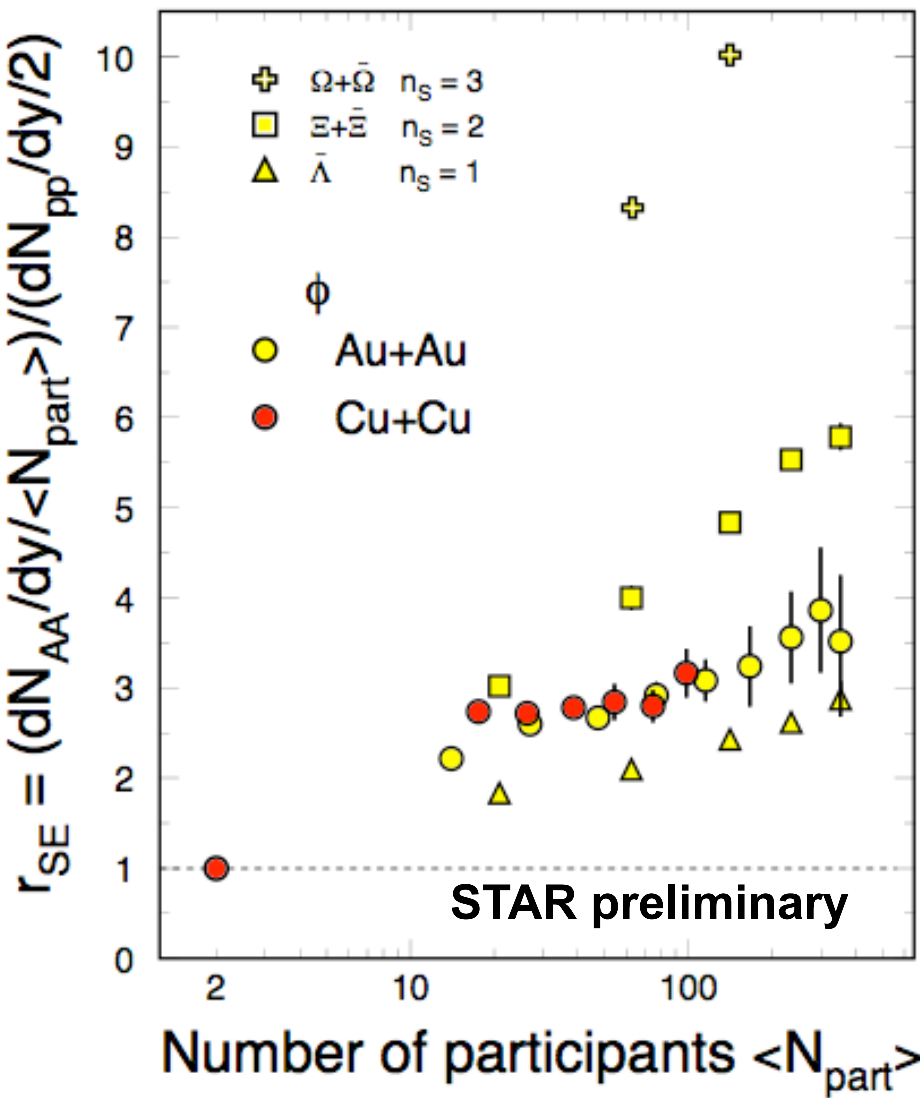
(1) Levy function well described the data (exponential in central and power-law-like in peripheral)

(2) Similar trend in Cu+Cu and Au+Au at the similar N_{part} and same collision energy

STAR: Phys. Lett. **B673**, 183(2009)
B. Mohanty, X.H. Shi

Strangeness Enhancement & ϕ-meson

B. Mohanty, , X.H. Shi



200 GeV collisions

- The productions of the multi-strange baryons Ξ, Ω are enhanced in heavy ion collisions compared to that of in p+p collisions

- The ϕ-meson productions are also enhanced. At this energy, since ϕ-mesons do not obey OZI, its production is not canonically suppressed ➔

The observed Strangeness Enhancements are NOT due to canonical suppression!

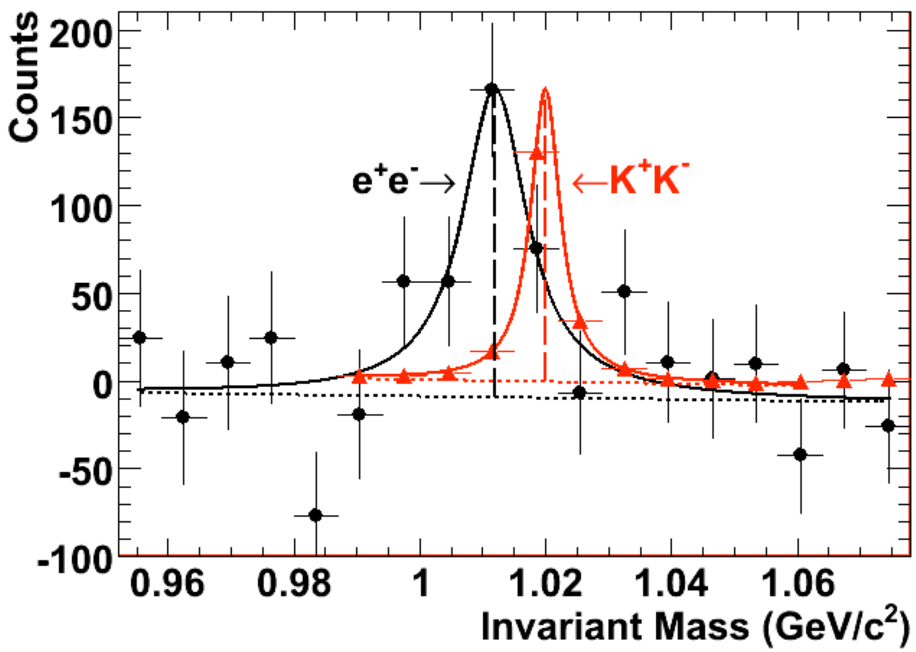
STAR:

- *PRL. **98** (2007) 062301 (nucl-ex/0606014)*
- *PRL **99**, 112301(07); nucl-ex/ 0705.2511*
- *Phys. Lett. **B673**, 183(2009).*

Next Step for ϕ-meson

In high-energy nuclear collisions:

(1) ϕ-meson are formed from s- and sbar-quark coalescence.
(2) Strangeness enhancement due to collision dynamics, not canonical suppression.
(3) Next step: $\phi \Rightarrow e^+e^-$ and compare with K^+K^- channel.

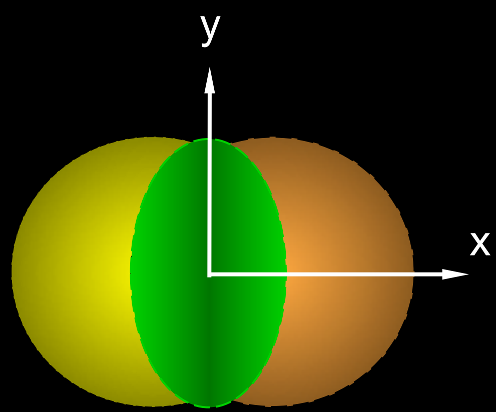


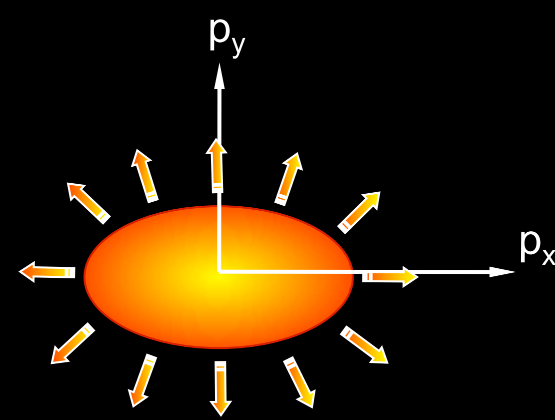
STAR Run8
200 GeV d+Au
preliminary results.

C. Jena, X.P. Zhang

Anisotropy Parameter v_2

coordinate-space-anisotropy ⇨ momentum-space-anisotropy



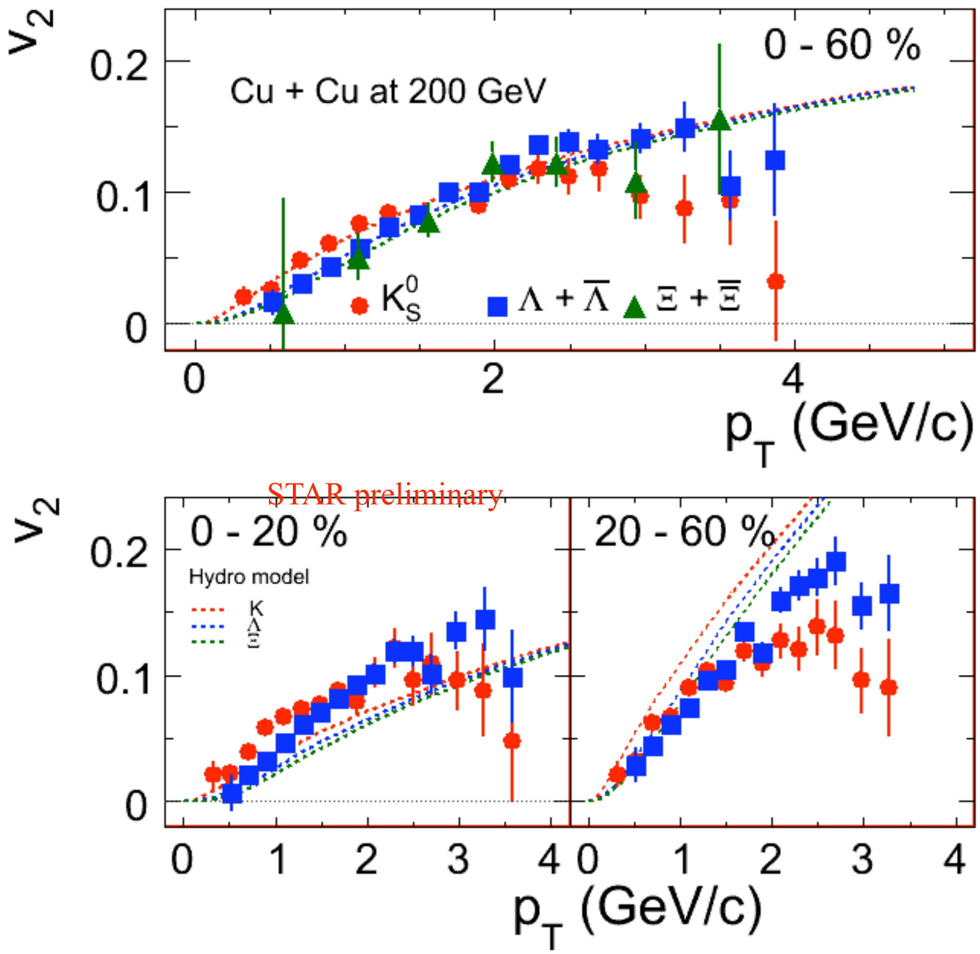


$$\varepsilon = \frac{\langle y^2 - x^2 \rangle}{\langle y^2 + x^2 \rangle} \qquad v_2 = \langle \cos 2\varphi \rangle, \quad \varphi = \tan^{-1}\left(\frac{p_y}{p_x}\right)$$

Initial/final conditions, EoS, degrees of freedom

$v_2(p_T)$ in Cu + Cu at 200 GeV

STAR QM2009: Y. Lu, ***S. Shi***
Ideal hydro: P. Huovinen



(1) p_T < 2 GeV/c
Smaller v_2 for heavier hadrons

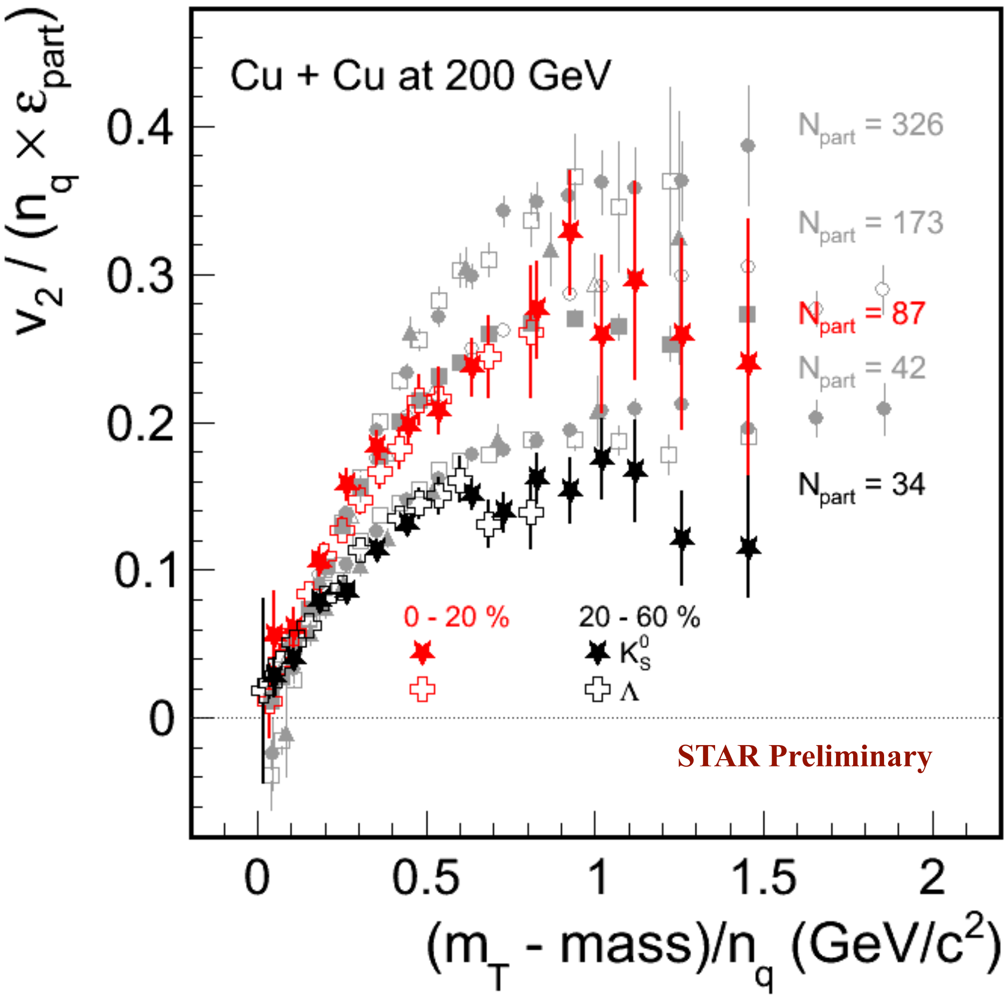
(2) p_T > 2 GeV/c
$v_2(\Lambda, \Xi) > v_2(K_S^0)$

(3) The ideal hydro fails to reproduce the centrality dependence
- Fluctuation of v_2?
- Viscosity ?
- Incomplete thermalization ?

Systematic v_2 Measurements

STAR Au + Au : PR**C77**, 054901 (2008): ***Y. Lu***, A. Poskanzer, S. Shi

STAR Preliminary Cu+Cu H. Masui, A. Poskanzer, ***S. Shi***



In 200 GeV Collisions

(1) The strength of v_2 is driven by the collisions centrality: stronger flow for more central collisions.

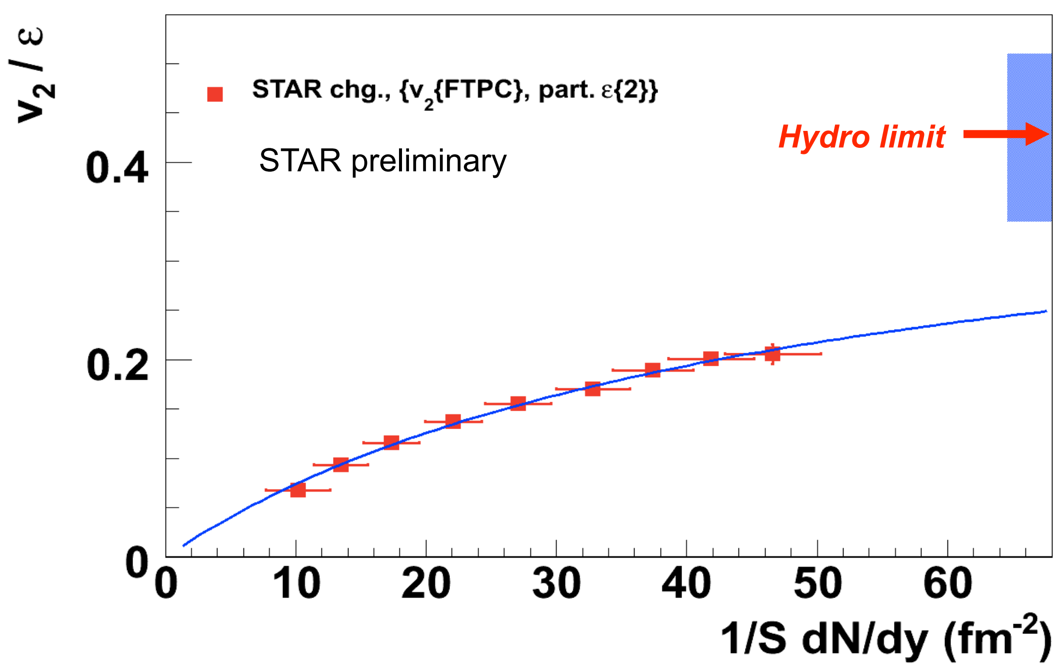
(2) Mesons and baryons behave similarly.

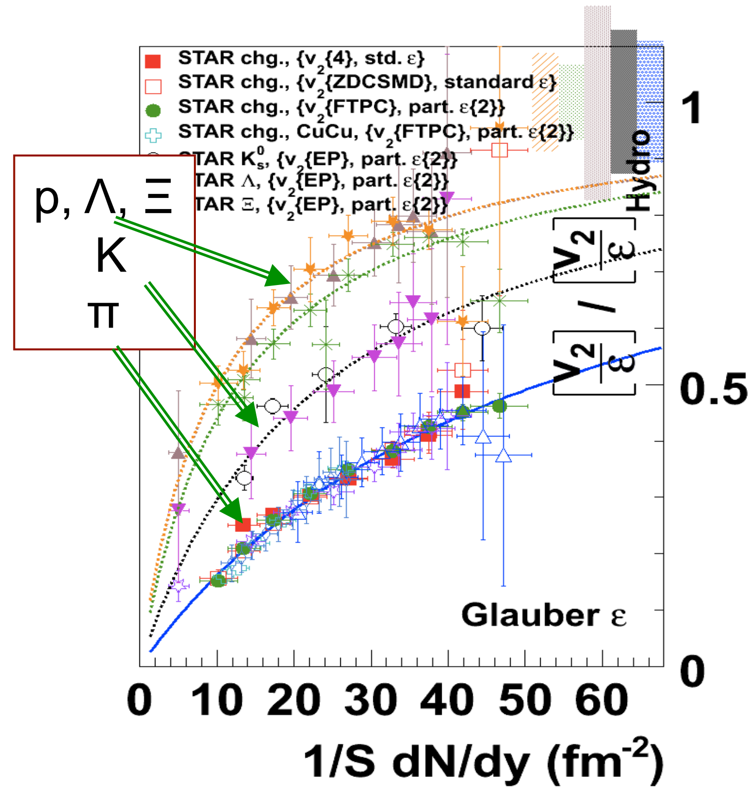
(3) At given centrality, all hadrons are scaled =>

Partonic Collectivity!

Test on Hydrodynamic Limit

H. Masui, S. Shi

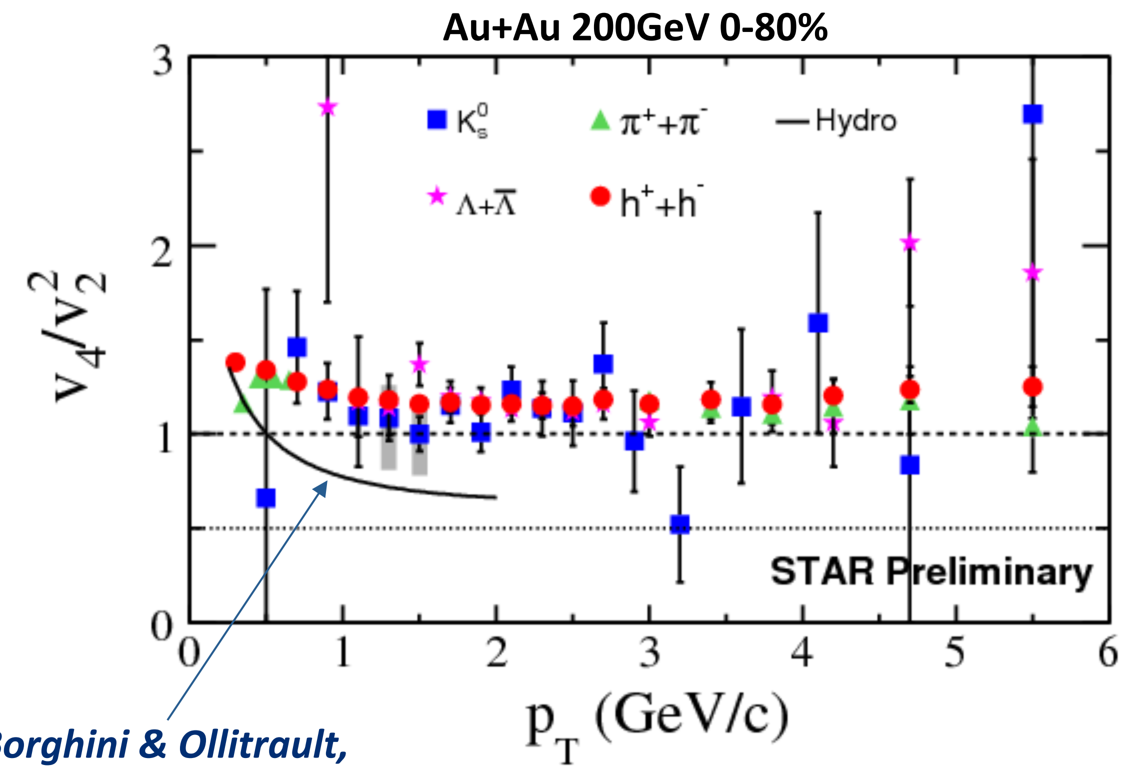




(1) Even in central Au + Au collisions, the results indicate that the system is still away, 10-30%, from hydro limit.

(2) Hadron mass dependence – not fully understood

Test of Ideal Hydro Predictions



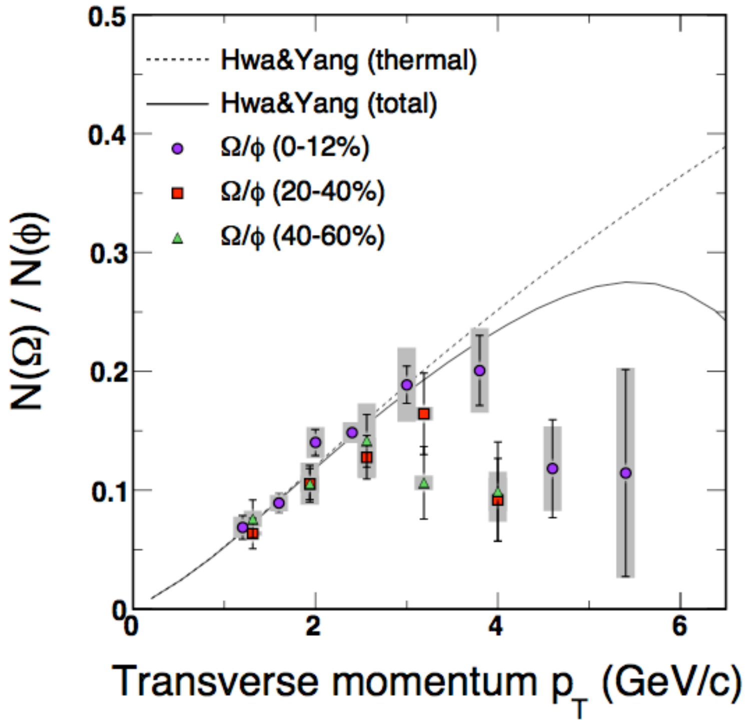
Borghini & Ollitrault, PLB 642(2006)227

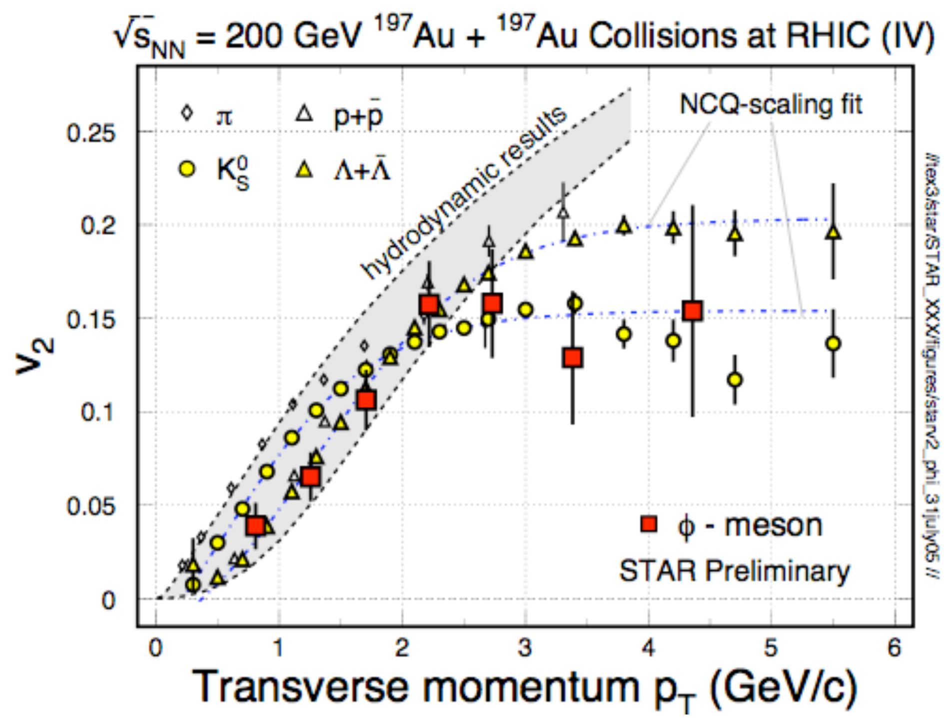
The v_4/v_2^2 ratio is larger than predictions from ideal hydrodynamics, which means that the system has not reached the ideal hydrodynamics.

N. Li

ϕ -meson Flow: Partonic Flow

S. Blyth, G. Odyneic



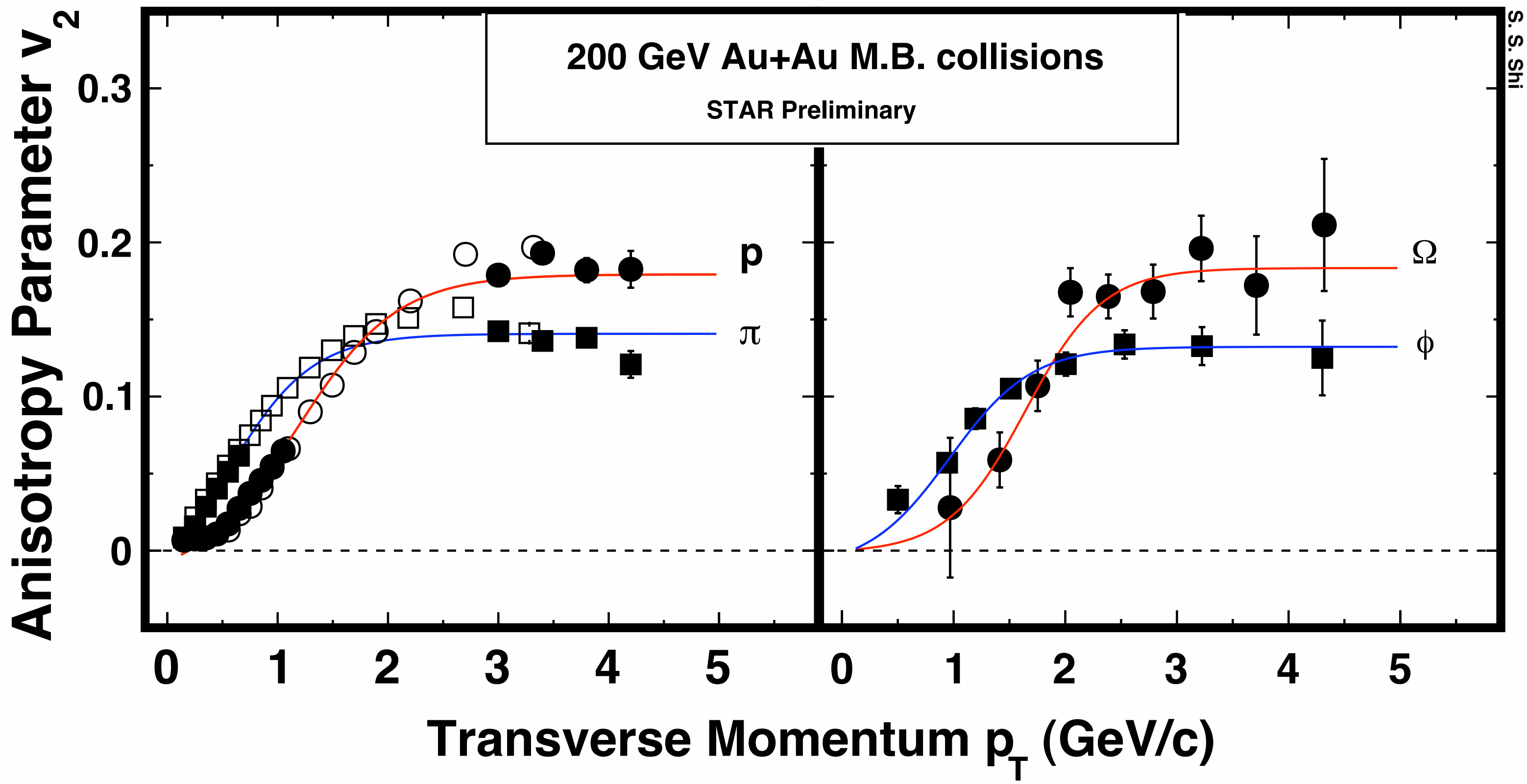


ϕ-mesons are special: - they are formed via coalescence with thermalized s-quarks

'They are made via coalescence of seemingly thermalized quarks in central Au+Au collisions, the observations imply *hot and dense matter with partonic collectivity* has been formed at RHIC'

STAR: Phys. Rev. Lett., ***99***, *112301(07), nucl-ex/0703033;* Phys. Lett. B612, 81(05)
2008: RHIC Ph.D Thesis Award.

New Results (Run7)



1) At low p_T - mass dependence
2) At intermediate p_T - clear difference between baryons and mesons
3) Hadrons with *u*-, *d*-, *s*-quarks show similar collectivity

Final word on partonic collectivity at RHIC!

STAR Preliminary, QM2009: ***S. Shi***

Next Step for v_2 Measurements

(1) Partonic collectivity measurements for light quarks (***u, d, s***) are done.

(2) Next Step: measure the heavy quark (c, b) collectivity to address the issue of local thermalization at RHIC. A crucial step toward understanding of QGP formation in high-energy nuclear collisions.

Summary

We have focused our physics program on the bulk properties (EoS) of the medium created in heavy ion collisions at RHIC:

- **Pressure gradient driven expansion**
- **Partonic collectivity**

Next step:

(1) Light quark thermalization: **heavy quark collectivity**

(2) QCD phase boundary: **n_q-scaling in v_2 , net-p Kurtosis**

(3) Chiral physics: **di-electron measurements σ, v_2, R_{AA}**